

ENDO LEAP FLIGHT TEST PLANNING

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ABSTRACT

The Atmospheric Interceptor Technology (AIT) program (formerly Endo LEAP) is focused on demonstrating strapdown seekers and strapdown guidance for very small miss distance intercepts at very high velocities against ballistic missiles within the atmosphere. This is being accomplished by advancing state-of-the-art technologies for small, lightweight, highly integrated kinetic energy kill vehicles (KV). Ground testing cannot fully duplicate the simultaneous interaction of the severe aerodynamic, aerothermal, and aero-optical conditions of hypervelocity flight within the atmosphere. Therefore, flight testing is required to fully validate the integrated technologies. The electro-optical (EO) flight testing is the impetus of this paper and can be broken down into two major elements: component flights and intercept flights. The component flights are utilized to resolve critical issues which will enable intercept flights, gather phenomenology data, and validate (EO) window concepts. In the intercept flights, prime contractor KV's will be flown against representative targets to demonstrate hit-to-kill (HTK) with aimpoint selection on the target lethal package. Initial studies indicate that both types of flights can be implemented utilizing boosters, launchers, and the organizational framework of existing interceptor systems.

PROGRAM OVERVIEW

The Ballistic Missile Defense Organization (BMDO) is presently involved in the acquisition and upgrade of several missile systems that operate within the atmosphere. The Army THAAD, PATRIOT, ERINT, ARROW, Corps SAM, GBI, the Navy Sea Based TMD, the Air Force Boost Phase Interceptor (BPI), and the National Laboratories Hypervelocity Missile (HVM) are all atmospheric missile systems

playing an important role in the BMDO program. These high speed atmospheric missile systems are an integral part of the present and future ballistic missile defense systems that will defend the United States and its allies against ever increasing and disbursed threats. In order to economically support these systems in providing an effective defense capability, a coordinated technology base which develops atmospheric interceptor technologies is essential. This robust technology base provides the hedge against advanced threats, provides the enabling capability to increase missile performance, and decreases deployment risk as component replacement opportunities arise.

BMDO's AIT program is the technology base that will be leveraged to provide the necessary upgrades to the above mentioned systems. The objective of the AIT program is to develop, design, fabricate and test lightweight hypersonic atmospheric technologies to support advanced ballistic missile interceptors. There are several elements to the AIT program. These elements involve prime contractor efforts to design and fabricate EO and millimeter wave (MMW) seekers and highly integrated KV's, Broad Area Announcement (BAA) contracts concentrating on EO and MMW component technologies, extensive ground testing of these concepts, and finally flight testing of the components and the KV's. The schedule in Figure 1 shows the relationship of these elements to one another and to the systems that they support.

The goal of the program is to integrate these technologies into a 25-30 kilogram experimental KV that demonstrates hypervelocity HTK within the atmosphere. The HTK must also be within a specified aimpoint radius on the target. Shown in Figure 2 are the velocities and altitudes of interest to the AIT program. The components and KV's are required to operate at these design points. The lower altitude design points are accomplished with direct ascent interceptors. The highest altitude and faster velocity design points are accomplished with lofted trajectory interceptors.

The prime contractor integrated KV efforts

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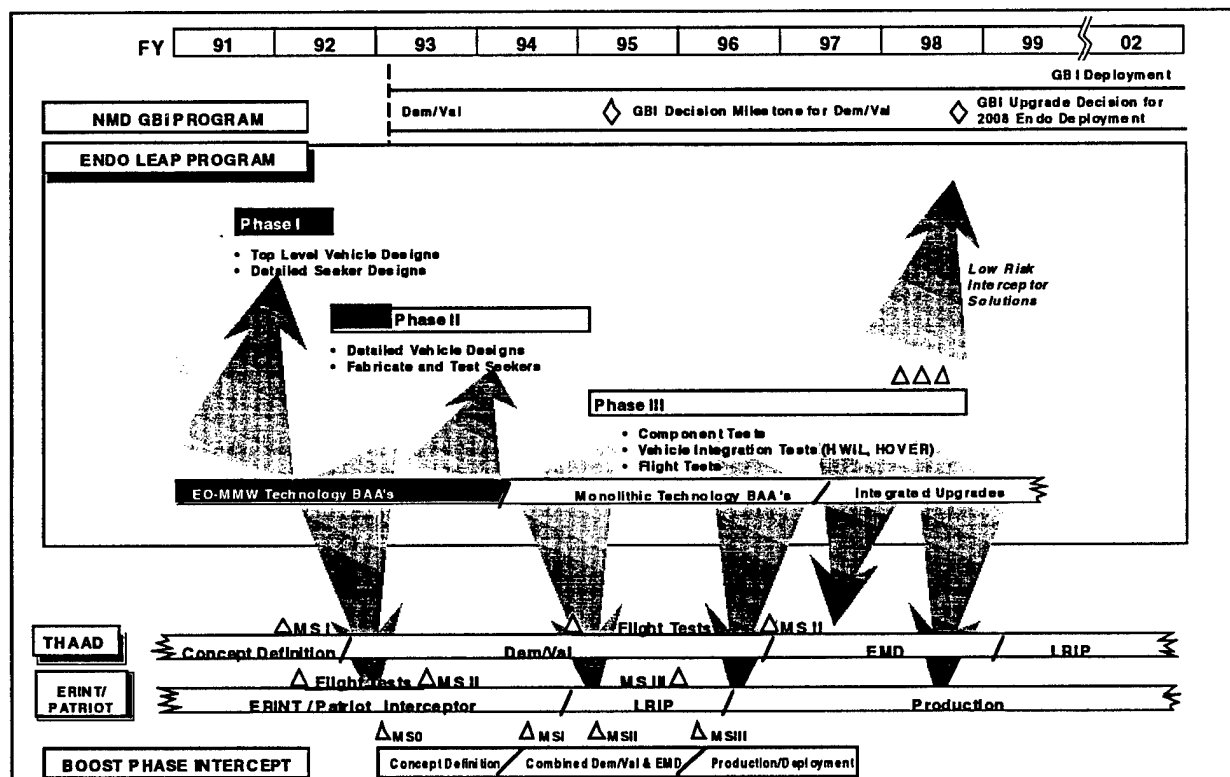


Figure 1 - AIT Application for NMD/TMD

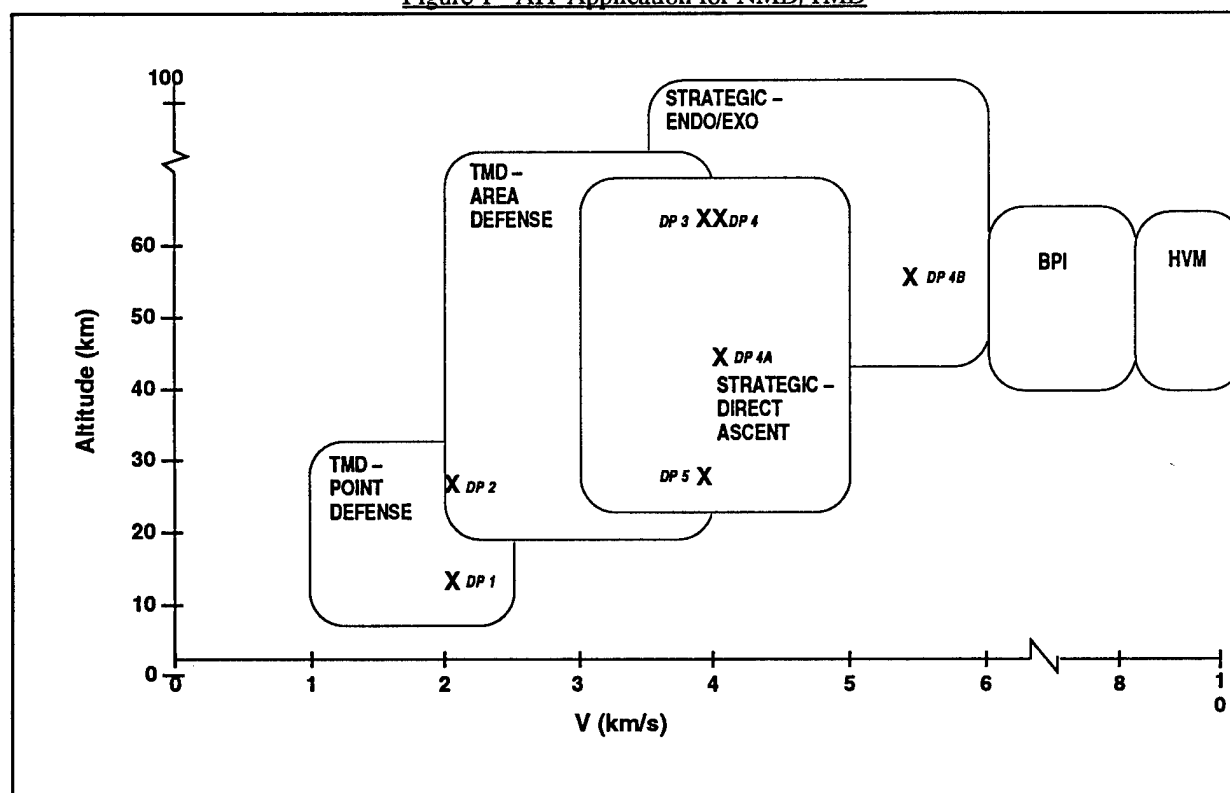


Figure 2 - AIT Design Requirements

are being performed by Lockheed Missiles and Space Company (LMSC) and McDonnell Douglas Aerospace (MDA). LMSC is working to provide an

EO and a MMW seeker, both of which are capable of being integrated on to a common vehicle that can perform either strategic or tactical intercepts. MDA is

CRITICAL ISSUES	GROUND TESTS										FLIGHT TESTS	
	LENS	ARC JET	WIND TUNNEL	LAB	FPA TEST FACILITY	STATIC TEST STAND	SLED TEST	SCF	HWIL	HOVER	COMPONENT FLIGHT TEST	HTK FLIGHT TEST
1. AERODYNAMICS			X ⁵				X ⁵				X	
2. AEROTHERMAL		X ¹		X ⁸							X	
3. AERO-OPTICS	X ³	X ²						X ⁴			X	
4. TRACK ACCURACY				X ⁴	X ⁴			X ⁴			X	
5. VEHICLE CONTROLS			X ⁵			X ⁶			X ⁶	X ⁶	X	
6. SHROUD SEPARATION			X ⁵				X ⁵				X	
7. INSTRUMENTATION & CALIBRATION					X ⁶	X ⁶					X	
8. PHENOMENOLOGY	X ⁷										X	

NOTES:

1. NO BLUR, JITTER	4. NO AERO-OPTICS, AEROTHERMAL EFFECTS	7. MOLECULAR DISASSOCIATION & IONIZATION ISSUE (TBD)
2. FLOWFIELD RADIANCE TBD	5. LIMITED MACH NO., PRESSURES & TEMPERATURES	8. MEAN TEMPERATURES WITHOUT GRADIENTS
3. NO AEROTHERMAL HEATING	6. NO AERODYNAMICS, AEROTHERMAL & AERO-OPTICS EFFECTS	

Figure 3 - Issue Resolution Testing Summary

providing an EO seeker and vehicle that addresses the faster velocity design requirements.

Approximately twenty-two BAA contracts were awarded with numerous aerospace contractors during FY91. These efforts concentrated on EO window cooling concepts, MMW radome concepts, and MMW technologies. Several of the concepts have demonstrated technical feasibility and have progressed into ground testing. The testing has included bench top testing, mechanical survivability, and thermal survival in arc jets. Aero-optics testing is scheduled to begin in late FY93.

CRITICAL ISSUES

Interceptors operating at hypervelocities within the atmosphere must overcome the severe aerothermal environment and the seeker must be able to compensate for the aero-optical effects to successfully accomplish their mission. The chemical, thermal, optical and structural effects primarily encompass the aero induced phenomenology that directly degrades the performance of seekers and KV's performing atmospheric missile intercept functions (reference 1). The specifics on the critical issues and the technology issues facing hypervelocity interceptors have been addressed in two earlier papers (references 2 & 3), so they will not be elaborated on here.

The velocity and weight objectives of the AIT program impose new challenges to the interceptor community. Empirical data does not currently exist to validate or verify the predictive codes used to design hypervelocity interceptors and to calculate the harsh operational environments.

An issue resolution approach has been formulated that includes very comprehensive ground testing. It is technically beneficial and financially critical to resolve as many issues as possible before attempting to perform the HTK intercept flights. Figure 3 shows the extent and type of testing required to reach resolution for each of the particular issues.

FLIGHT TEST METHODOLOGY AND APPROACH

The purpose of doing the flight tests is to validate the designs, analysis, simulations, and ground tests that show that hypervelocity HTK intercepts with small KV's can be accomplished utilizing strapdown seekers and strapdown guidance. These flights also provide the data necessary to resolve critical issues at environmental conditions that can not be fully duplicated or experienced except in flight. The AIT component and intercept flight tests will validate aperture technologies, incrementally demonstrate the capability of strapdown seekers and guidance, and ultimately demonstrate that the integrated vehicles meet all design requirements.

This is a low risk, high payoff method of demonstrating advanced technologies for transfer to the systems mentioned earlier.

Ideal Approach

The ideal approach to implementing the component and intercept flights would involve utilizing a single booster stack capable of delivering the component payload or the KV to all of the required design points. All of these flights would originate from a single test range that would allow intercepts of a wide range of representative targets. Six different classes of flights would be possible: direct ascent MMW component flights at 2 km/s, direct ascent EO component flights at 4 km/s, lofted EO component flights in excess of 4 km/s, direct ascent MMW intercept flights at 2 km/s, direct ascent EO intercept flights at 4 km/s, and lofted EO intercept flights in excess of 4 km/s. Essentially this operation would entail just changing the payload and flying a different trajectory. This approach would allow for resolution of critical issues associated with each particular design point. The attractiveness of this approach lies in the commonality of the booster hardware, the reuse of demonstrated and proven hardware and launch capabilities, and the completeness of collecting all pertinent data.

Unfortunately, technical feasibility, treaty implications, and cost concerns prohibit the implementation of this approach. A booster with this range of flexibility does not exist. Even if such a booster existed, its use to intercept both strategic and theater targets would not be Anti-ballistic Missile (ABM) treaty compliant. Also the cost of doing all of the design point scenarios quickly becomes prohibitive.

Therefore, a realistic approach has been developed which will provide the data required to resolve critical issues and incrementally step towards full validation in a timely and cost efficient manner. The following sections will detail the plans for EO component and EO integrated KV intercept flights. The MMW flights will be the subject of future papers.

Component Flights

There is a definite need to resolve as many of the critical issues as possible before attempting to perform the high cost intercepts with the full up highly integrated prime contractor KV's. As discussed earlier, even with extensive and comprehensive ground testing, there are several conditions which cannot be duplicated or simulated entirely, except by experiencing the actual flight environment. Very little flight data exists for the regimes of interest to the AIT program. The KITE-2A flight produced the most

severe window heating environment experienced to date (reference 4). However, the aerothermal environment that the AIT EO KV's are being designed for is several times more severe. It is therefore extremely advantageous to experience these severe environments and collect data prior to going after targets.

Viewing the design point requirements, dynamic pressure, and heat flux plot of Figure 4 characterizes the particular environment for different interceptor velocities and altitudes. The most stressing from an aerothermal standpoint is design point 5 which approaches 1000 W/cm^2 heating for a window on a representative forebody cone angle. It can be seen that different velocities and altitudes can be simulated by moving along the dynamic pressure and heat flux contours. For this reason, it is not mandatory to fly exactly through the design point to experience the environment of interest at that design point. Therefore it may be possible to utilize existing booster systems and shape the flyout trajectory to produce the environment of interest.

The BAA EO window concepts have undergone ground testing in the lab, at arc jet facilities, and will be tested beginning in late FY93 at the Aero-optics Evaluation Center (AOEC). The results to date indicate that the concepts can survive and function operationally in the AIT required environments. Flight testing of these windows represents the next logical step towards full validation and verification of each concept. The schedule for these window component flights is shown in Figure 5.

To minimize complexity and costs, all of the window components will be flown on a common tetracone forebody. The tetracone has four flats for windows and instrumentation. Windows for each flight will be mounted on two opposing flats. Instrumentation and material coupons will be mounted on the other flats.

This forebody will be a larger scaled model of a representative AIT KV forebody. The greater volume eliminates many of the packaging concerns and allows for multiple windows to be flown on a single flight. The option exists to fly various nosetips. A radiometer/spectrometer data collection instrument contained within a very rigid structure and closely coupled with an IMU will be utilized to look through the selected window concepts.

The first flight configuration will feature the two AIT prime contractor window designs. The LMSC internally water cooled silicon window and the MDA externally helium cooled sapphire window will be mounted on opposite flats of the tetracone. One of the other flats will be heavily instrumented to gather pressure, heat flux, temperature, and structural measurements for characterization of the flight environment. The remaining flat will contain material

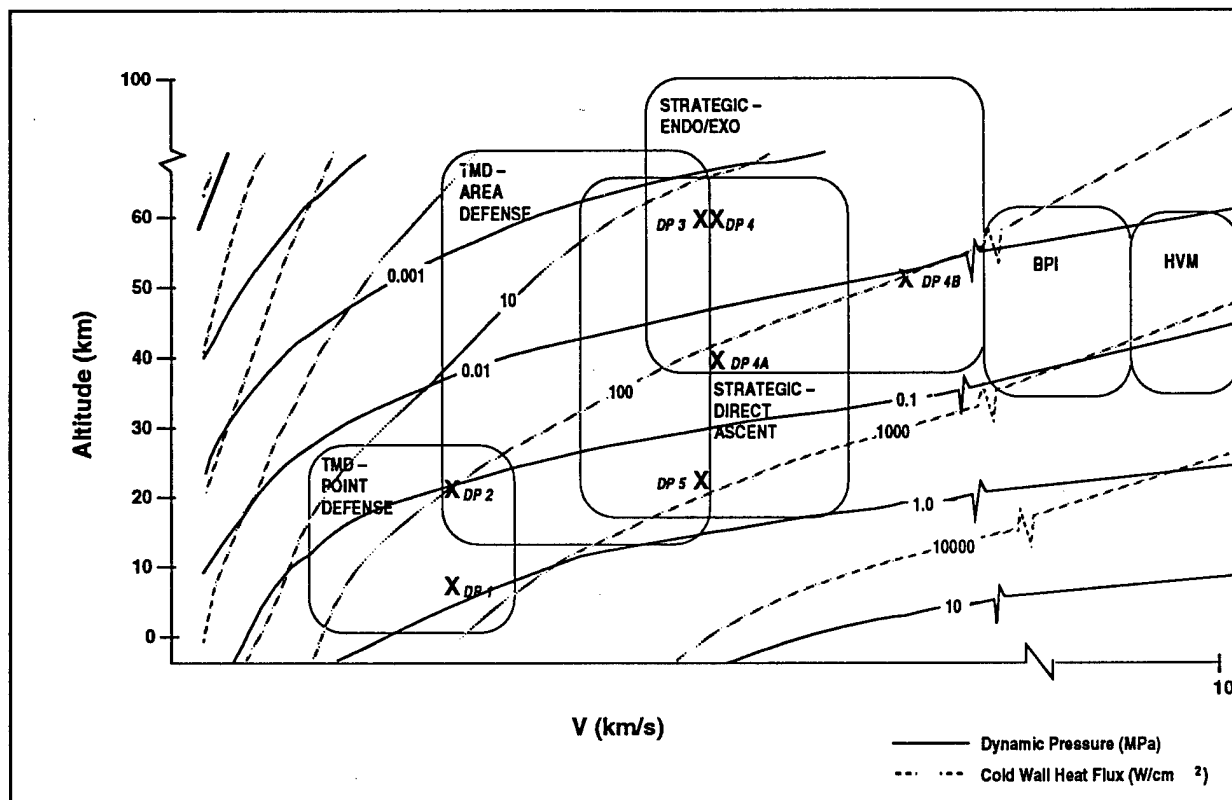


Figure 4 - AIT Design Requirements

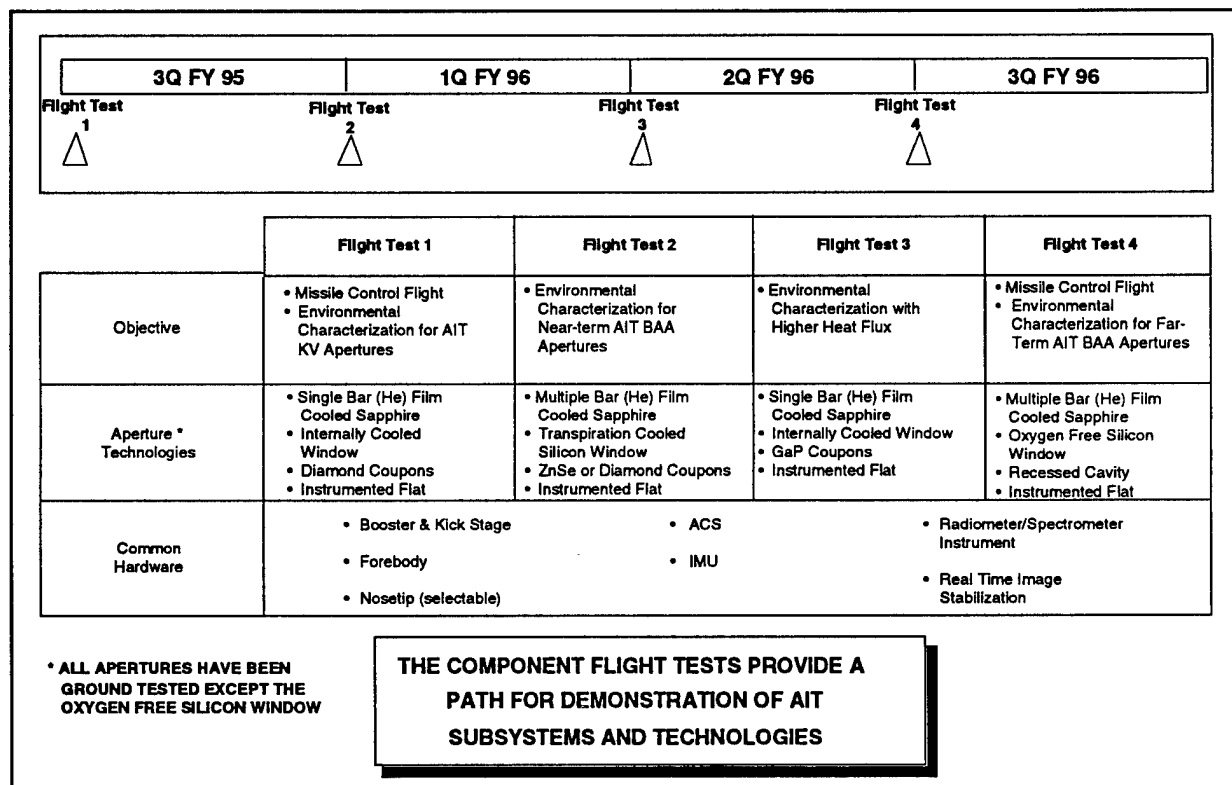


Figure 5 - AIT Component Flight Test

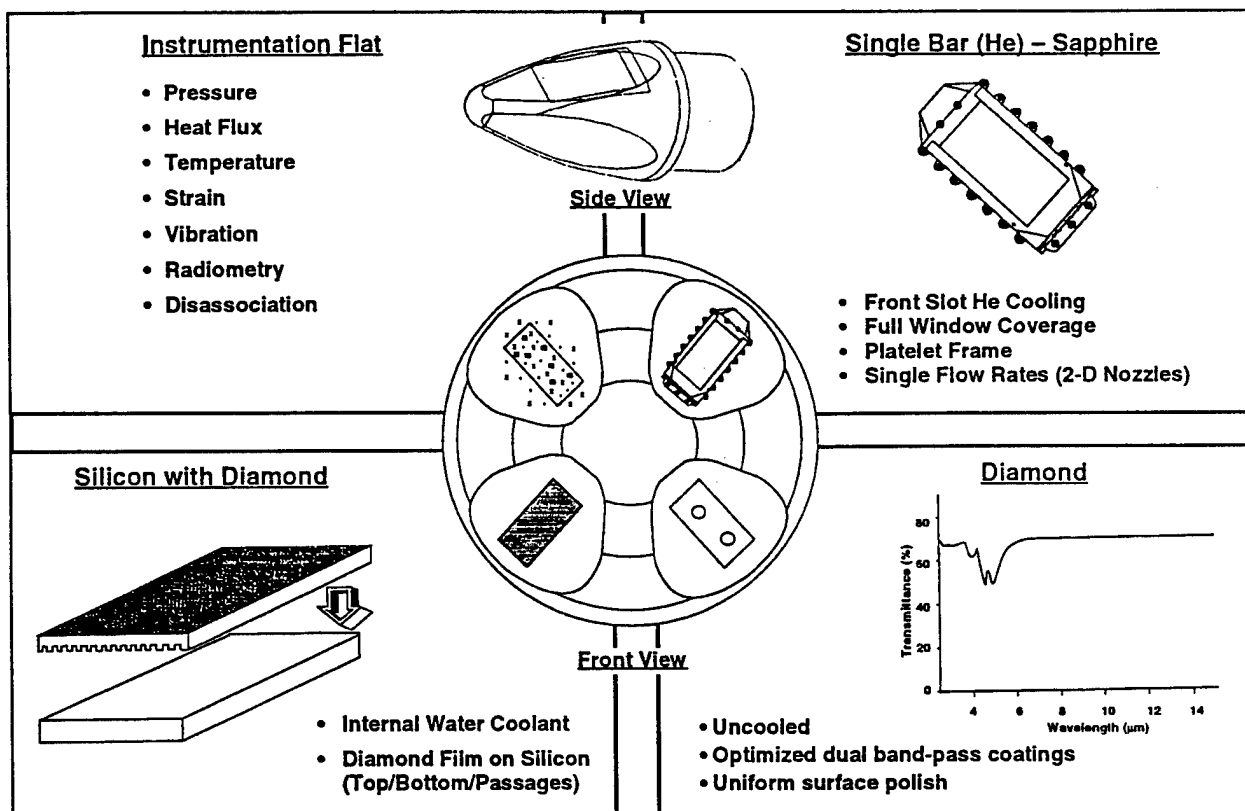


Figure 6 - AIT Component Flight Test Aperture Hardware

witness samples. Figure 6 shows this configuration.

Flights two through four are configured in a similar manner. The windows move from near term BAA concepts such as the transpiration cooled silicon window to further term concepts such as a recessed cavity window or an uncooled diamond window. The primary objective of these flights will be the environmental characterization on each of the windows. A key element of these flights is the fact that only windows and window frames are changed from flight to flight.

The environments on the forebody can be controlled by shaping the flyout trajectory and by limiting the exposure time seen by the windows. A typical flight scenario would expose the window to the atmosphere for several seconds. During this timeframe, the data collection instrument would look through one of the windows, utilize the cold gas ACS to perform a roll maneuver if necessary, then look through the other window. It should be noted that there are no conventional targets in any of these flights. The data collection instrument would be gathering data on well characterized celestial bodies.

These component flights provide the validation of the window designs, begin to fill the void of data at these atmospheric environments, and provide the confidence and the data required to move toward full strapdown seeker systems.

Intercept Flights

The intercept flights will utilize AIT prime contractor KV's to demonstrate hypervelocity HTK with aimpoint selection against representative ballistic missile targets within the atmosphere. Three classes of intercept flights will be demonstrated as follows: direct ascent intercepts utilizing a MMW seeker, direct ascent intercepts utilizing an EO seeker, and lofted intercepts utilizing an EO seeker. The component flights addressed earlier and the implementation approach to be discussed later is focused on the direct ascent EO flights. The schedule for these EO intercept flights is shown in Figure 7. Details for the other two classes of intercept flights are being worked but will not be presented in this paper.

Two different prime contractor KV's are indicated for the intercept flights. The initial flight for both LMSC and MDA would be a control test flight. Subsequent flights would intercept representative targets at various velocities and altitudes. The first intercept would occur at the most benign of the AIT design point conditions, but as of yet to be demonstrated by any other technology demonstration or missile system. Each succeeding flight would increase toward more environmentally stressing conditions.

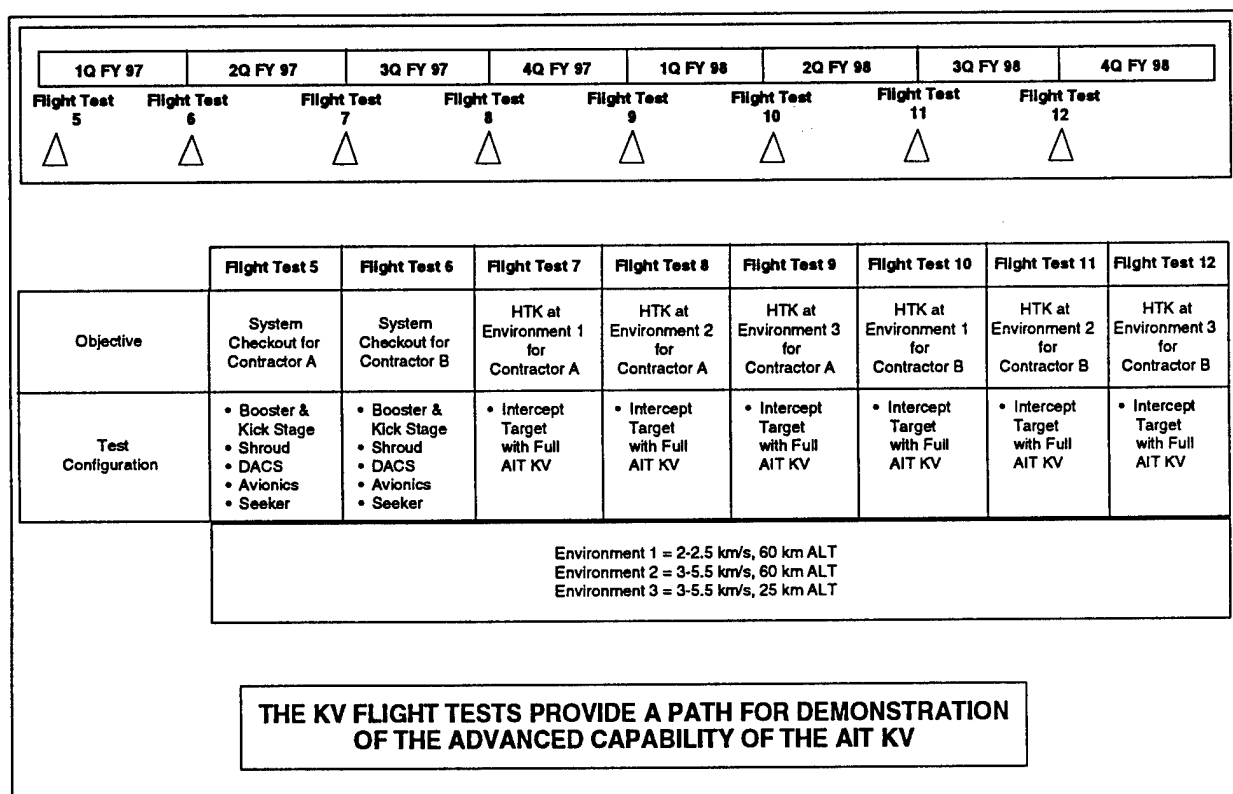


Figure 7 - AIT KV Flight Test

Implementation

In order to minimize the cost and technical risk of these flight tests, it will be extremely beneficial to leverage existing launch capabilities. This includes booster hardware, ground support hardware, launch teams, and all of the associated equipment and experienced personnel required to launch an interceptor. Use of an existing framework will save both time and money. It reduces the risk associated with launching unproven boosters that have no demonstrated history.

Several booster systems appear feasible towards obtaining the flight environments of interest if they are augmented with a kick stage. These candidates are interceptor systems that presently exist or that are being acquired. THAAD, PATRIOT, Standard Missile, SRAM and other booster stacks offer the booster and launch framework that is desired. However it is important that there be minimal disruption to the selected missile program by the AIT flight tests.

The THAAD system will be used for illustrative purposes. A high degree of confidence will have been established and demonstrated in the THAAD booster and launch system when the AIT flights are scheduled to fly. Looking specifically at the missile, it can be seen that the THAAD KV is longer and has a larger diameter than the AIT KV. Thus, the forebody under the shroud is also bigger.

These are advantageous characteristics to the AIT flight test program.

For the component flights, a kick stage and a larger version of the AIT forebody and aftbody can be fit into the same space as that which is allocated for the THAAD KV as seen in Figure 8. As described earlier, the tetracone forebody will have two windows mounted on opposite flats. Also in the forebody will be the combination radiometer/spectrometer data collection instrument and IMU. The aftbody contains the cold gas ACS, coolant tanks (if needed for the nosetip and windows), electronics, and telemetry package. The larger forebody and aftbody, along with the absence of a divert system, eliminate the compact packaging problems associated with the full up KV and provide the necessary real estate and volume to utilize off the shelf componentry.

The intercept flights will operate in much the same manner. The AIT full up KV will be stacked along with the kick stage on the THAAD booster. Operation of the booster and kick stage will have been demonstrated in the prior component flights. The AIT KV and kick stage are roughly the same length as the THAAD KV so there should not be any problems with the launcher.

This implementation approach to flight testing will continue to be pursued. It focuses on: utilizing available boosters and kick stages to obtain the environments applicable to the diverse set of design points, minimizing disruption to the selected missile program, collecting data on the window

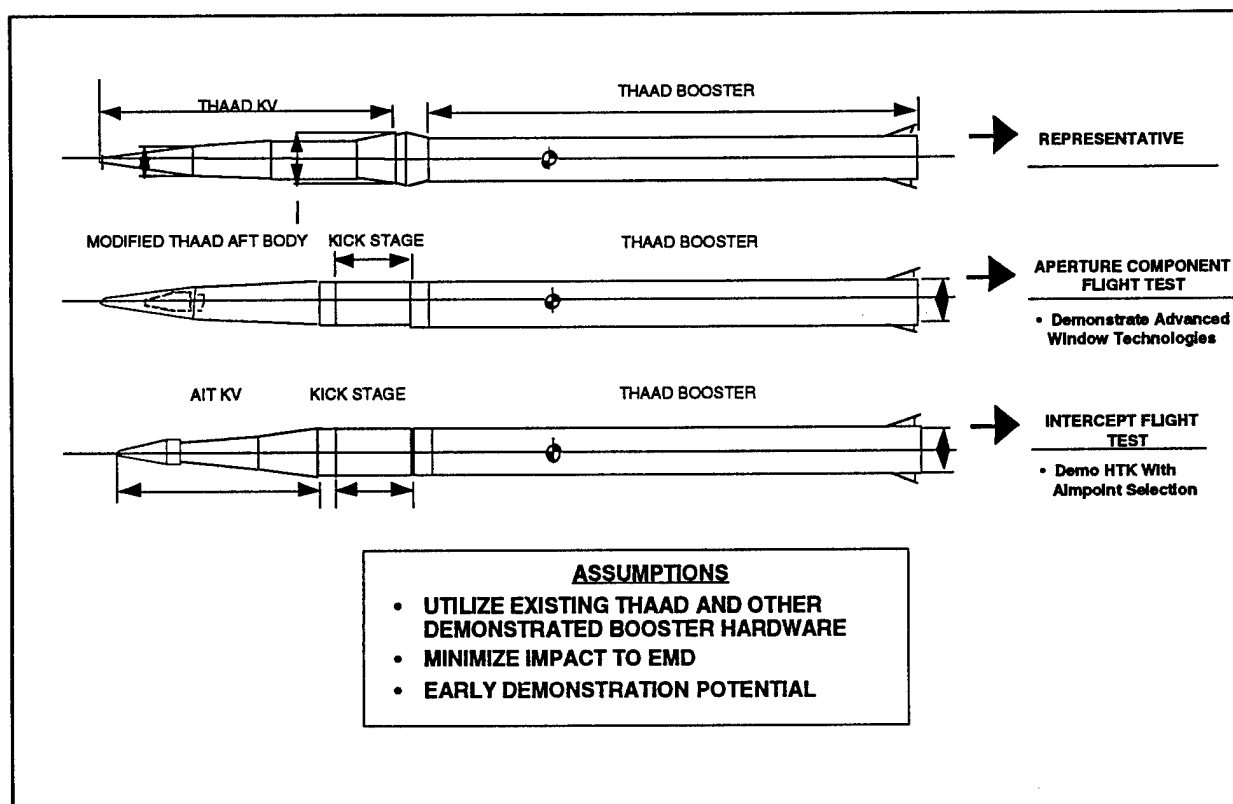


Figure 8 - Flight Test Implementation

components to provide inputs to the AIT designs and other atmospheric missiles, providing early component upgrades to current interceptor system capabilities, and maintaining flexibility to utilize a variety of boosters.

CONCLUSIONS

The AIT program is maturing the technologies and providing the technology base that is required to provide upgrades to present and future NMD and TMD (including BPI) systems for the Army, Air Force, and Navy that are being developed under BMDO guidance. As the window and vehicle components successfully progress past the ground testing phase, flight testing is required to fully validate these technologies. The flight test planning presented offers a realistic approach to resolve critical issues associated with hypervelocity intercepts within the atmosphere, validates window designs, and provides a path to demonstrate full strap down seekers and guidance. Utilizing boosters from existing systems is a viable solution to producing the increased velocities and more stressing environments required to fully validate and verify the AIT program technologies for tomorrow's missile systems.

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